

# Exotic narrow resonance searches in the system $\Lambda K_s^0$ in p+propane collisions at 10 GeV/c

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## Abstract

Experimental data from the 2m propane bubble chamber have been analyzed to search for an exotic baryon states, in the  $\Lambda K_s^0$  decay mode for the reaction p+C<sub>3</sub>H<sub>8</sub> at 10 GeV/c. The invariant mass spectrum  $\Lambda K_s^0$  observe a narrow peaks at  $1750 \pm 18$ ,  $1795 \pm 18$ ,  $1850 \pm 19$  MeV/c<sup>2</sup> and full widths of  $\Gamma_{exp.} = 32 \pm 6$ ,  $44 \pm 15$ ,  $29.0 \pm 8$  MeV/c<sup>2</sup>. The statistical significance of these peaks has been estimated as 5.6, 3.3 and 3.0 S.D., respectively. There are the small enhancements in mass regions of (1650-1675) and (1925-1950) /<sup>2</sup>. These would be candidates for the  $N^0$  or the  $\Xi^0$  pentaquark states.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energies, JINR.

## 1 introduction

Several models predict the multiplet structure and characteristics of pentaquarks for example the chiral soliton model, the uncorrelated quark model, correlated quark models, QCD sum rules, thermal models, lattice QCD etc[1]-[18]. Multi-quark states, glueballs and hybrids have been searched for experimentally for a very long time, but none is established.

Results from a wide range of recent experiments[19] are consistent with the existence of an exotic S=+1 resonance, the  $\Theta + (1540)$  with a narrow width and a mass near 1540 MeV [1]. Results from this experiment:  $M_{\Theta^+} = (1540 \pm 8)$  MeV/c<sup>2</sup>,  $\Gamma_{\Theta^+} = (9.2 \pm 1.8)$  MeV/c<sup>2</sup> (PDG-04:  $\Gamma_{\Theta^+} = (9.2 \pm 0.3)$  MeV/c<sup>2</sup>).

However, recent significant advances in theoretical and experimental work led to a number of new candidates in the last 2 years of searches. Candidates for other pentaquarks have been presented recently, in particular for the  $\Xi^{--}(1862)$ ,  $\Xi^-(1850)$ ,  $\Xi^0(1864)$ [20] and the  $\Theta_c^0(3099)$  [21]. Preliminary results of the STAR (Solenoidal Tracker At RHIC) on a search for the  $\Xi^0$  I=1/2 as well as for the  $N^0$  or the  $\Xi^0$  pentaquark states in the decay mode  $\Lambda K_s^0$  with the mass  $1734 \pm 0.5 \pm 5$  MeV/c<sup>2</sup> is presented in the article[22]. A significant signal for  $\approx \Xi^0(1750) \rightarrow \Xi^- \pi^+$  was observed[23].

## 2 Experiment

The JINR 2m bubble chamber is the most suitable instrument for this purpose [24]. The experimental information of more than 700000 stereo photographs are used to select the events with  $V^0$  strange particles.

The events with  $V^0$  ( $\Lambda$  and  $K_s^0$ ) were identified by using the following criteria [24]:

1)  $V^0$  stars from the photographs were selected according to  $\Lambda \rightarrow \pi^- + p$ , neutral  $K_s \rightarrow$

$\pi^- + \pi^+$  or  $\gamma \rightarrow e^+ + e^-$  hypothesis. A momentum limit of  $K_s^0$  and  $\Lambda$  is greater than 0.1 and 0.2 GeV/c, respectively ; 2)  $V^0$  stars should have the effective mass of  $K_s^0$  and of  $\Lambda$ ; 3) these  $V^0$  stars are directed to some vertices(complanarity); 4) they should have one vertex, a three constraint fit for the  $M_K$  or  $M_\Lambda$  hypothesis and after the fit,  $\chi_{V^0}^2$  should be selected over range less than 12; 5) The analysis has shown[24] that the events with undivided  $\Lambda, K_s^0$  were appropriated events as  $\Lambda$

The effective mass distribution of 8657-events with  $\Lambda$ , 4122-events with  $K_s^0$  particles are consistent with their PDG values(Fig.1). The effective mass resolution of  $\Lambda K_s^0 p$  system was estimated to be on the average 1%.

Each  $V^0$  event weighted by a factor  $w_{geom} (=1/e_\tau)$ , where  $e_\tau$  is the probability for potentially observing the  $V^0$ , it can be expressed as

$$e_\tau = \exp(-L_{min}/L) - \exp(-L_{max}/L),$$

where  $L(=cp\tau/M)$  is the flight length of the  $V^0$ ,  $L_{max}$  the path length from the reaction point to the boundary of fiducial volume, and  $L_{min}$ (0.5 cm) an observable minimum distance between the reaction point and the  $V^0$  vertex.  $M, \tau$ , and  $p$  are the mass, lifetime, and momentum of the  $V^0$ . The average geometrical weights were  $1.34 \pm 0.02$  for  $\Lambda$  and  $1.22 \pm 0.04$  for  $K^0$ . Figure 2 compares the momentum,  $\cos\theta$  in the c.m. nucleon-nucleon system, transverse momentum( $p_t$ ) and longitudinal rapidity distributions of  $\Lambda$  and  $K_s^0$  for experimental events (solid line) and those simulated by the FRITIOF model[26, 27] (broken line) in p+C interactions. From Fig.2 one can see that the experiment is satisfactorily described by the FRITIOF model.

The estimation of experimental inclusive cross sections for  $\Lambda$  and  $K_s^0$  production in the  $p^{12}C$  collision is equal to  $\sigma_\Lambda = 13.3 \pm 1.7$  mb and  $\sigma_{K_s^0} = 3.8 \pm 0.6$  mb, respectively [24].

### 3 $\Lambda K_s^0$ - spectrum analysis

The total experimental background has been obtained by three methods(Fig.3). In the first method, the experimental effective mass distribution was approximated by the polynomial function after cutting out the resonance ranges because this procedure has to provide the fit with  $\chi^2=1$  and polynomial coefficient with errors less than 30%. This distribution was fitted by the six-order polynomial. The second of the randomly mixing method of the angle between  $K_s^0$  and  $\Lambda$  for experimental events is described in [25]. Then, these background events were analyzed by using the same experimental condition and the effective mass distribution ( $\Lambda K_s^0$ ) was fitted by the six-order polynomial. The third type of background for ( $\Lambda K_s^0$ ) combinations has been obtained by FRITIOF model[26, 27](Fig.3b). In all figures the background distribution has been normalized to the experimental distribution. The analysis of background done by three methods has shown that there are not observable structure in range of peaks. The analysis of the experimental data are based on the polynomial method.

Figure 3 shows the invariant mass of 1012 ( $\Lambda K_s^0$ ) combinations with bin sizes 10 MeV/ $c^2$ . The values for the mean position of the peak and the width obtained by using Breit Wigner fits. There are significant enhancements in mass regions of 1750, 1795 and 1835 MeV/ $c^2$ (Fig.3). Their excess above background by the first method is 4.0, 2.7, 3.0 S.D.. There is small enhancement in mass region of 1935 MeV/ $c^2$ . The simulation with

Table 1: The statistical significance, the width( $\Gamma$ ) and the effective mass resonances in collisions of protons with propane at 10 GeV/c

Resonance Decay Mode	$M_{\Lambda K_s^0}$ MeV/ $c^2$	Experimental width $\Gamma_e$ MeV/ $c^2$	$\Gamma$	The maximal statistical significance $N_{sd}$
$K_s^0 \Lambda$	1750 $\pm$ 18	32 $\pm$ 6	14 $\pm$ 6	5.6
$K_s^0 \Lambda$	1795 $\pm$ 18	44 $\pm$ 15	26 $\pm$ 15	3.3
$K_s^0 \Lambda$	1850 $\pm$ 19	28 $\pm$ 7	10 $\pm$ 7	3.0

FRITIOF model for ( $\Lambda K_s^0$ ) combinations has shown in Fig.4 that there are not significant reflection from well known resonances in this distribution. Similar results have obtained when using a Breit Wigner distribution and different bin sizes.

Figure 5 shows the invariant mass of ( $\Lambda K_s^0$ ) with bin sizes 11 MeV/ $c^2$ . There are significant enhancements in mass regions of 1670, 1750, 1795 and 1850 MeV/ $c^2$  (Fig.5). Their excess above background by the first method is 2.9, 4.7, 2.3 and 2.4 S.D..

The effective mass distribution of ( $\Lambda K_s^0$ ) with bin size 18 MeV/ $c^2$  is shown in Fig.6. This bin size is consistent with the experimental resolution within the errors. The solid curve is the sum of the background by the first method and 2 Breit-Wigner resonance curves (Fig 6). There are significant enhancements in mass regions of 1750 and 1795 MeV/ $c^2$ . Their excess above background by the first method is 5.6 and 3.3 S.D.. respectively. There are negligible enhancements in the mass regions of 1680, 1860 and 1950 MeV/ $c^2$ .

## 4 Conclusion

A number of peculiarities were found in the effective mass spectrum of system  $\Lambda K_s^0$  in ranges of: (1740-1750), (1785-1800) and (1835-1860) MeV/ $c^2$  in collisions of protons of a 10 GeV/c momentum with propane nuclei. The detailed research of structure of mass spectrum has shown, that the maximum statistical significance has been obtained in effective mass ranges submitted in table 1. There are small enhancements in the mass spectrum regions of (1650-1675) and (1925-1950) MeV/ $c^2$ .

The preliminary total cross section for  $N^0(1750)$  production in  $p+C_3H_8$  interactions is estimated to be  $\approx 30\mu b$ .

The  $N^0$  can be from the antidecuplet, from an octet (D. Diakonov, V. Petrov, [1], V. Guzey and M. Polyakov, [2]) or an 27-plet (J. Ellis et al, [8]). On the other hand, Jafe and Wilczek predicted a mass around 1750 MeV and a width 50 % larger for these states than that of the  $\Theta^+$  ([5]).

These peaks are possible candidates for two pentaquark states: the  $N^0$  with quark content udsds decaying into  $\Lambda K_s^0$  and the  $\Xi^0$  quark content udssd decaying into  $\Lambda \bar{K}_s^0$ , which are agreed: with the calculated rotational spectra  $N^0$  and  $\Xi^0$  spectra from the theoretical report of D. Akers, [28] (Fig.7) and with  $\Theta^+$  spectra from the experimental reports of Yu.A. Troyan et.al., JINR, D1-2004-39, Dubna, 2004 and P. Aslanyan JINR, E1-2004-137, 2004.

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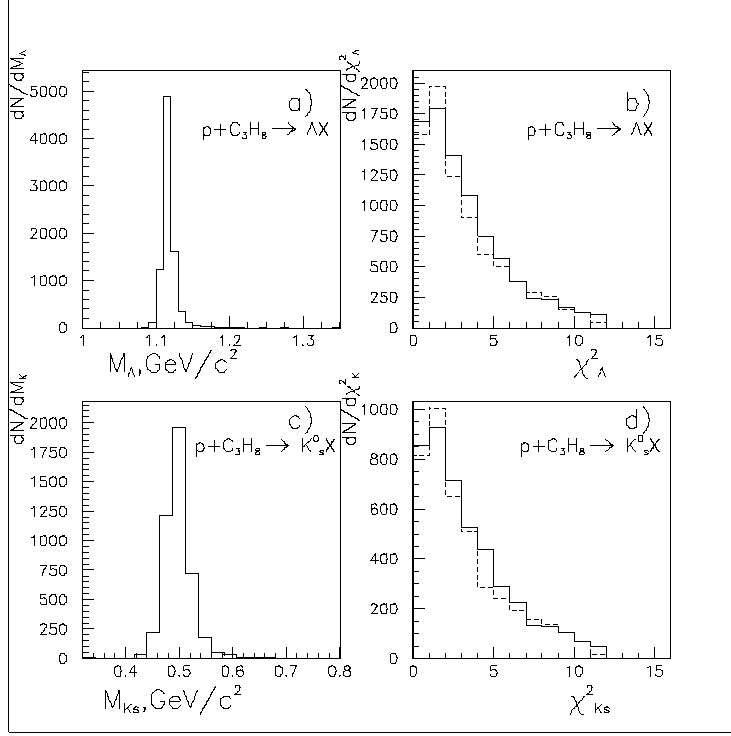


Figure 1: The distribution of experimental  $V^0$  events produced from interactions of beam protons with propane: a) for the effective mass of  $M_\Lambda$ ; b) for  $\chi_\Lambda^2(1V - 3C)$  of the fits via the decay mode  $\Lambda \rightarrow \pi^- + p$ ; c) for the effective mass of  $M_{K_s^0}$ ; d) for  $\chi_{K_s^0}^2(1V - 3C)$  of the fits via decay mode  $K_s^0 \rightarrow \pi^- + \pi^+$ . The expected functional form for  $\chi^2$  is depicted with the dotted histogram.

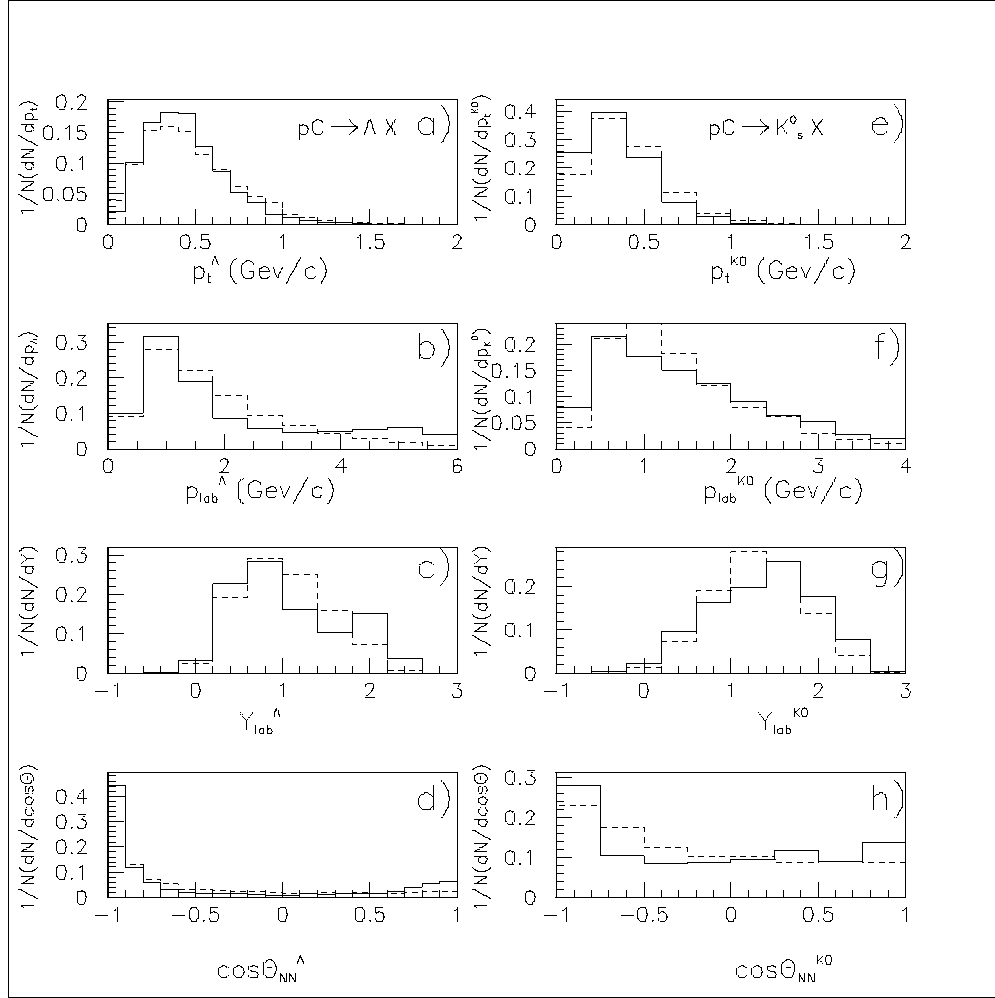


Figure 2: Experimental(solid) and simulation by FRITIOF model(dashed) distributions of  $\Lambda$  - hyperons and  $K_s^0$ - mesons in p+C interaction at 10 GeV/c: a)and e) by the transverse momentum ( $p_t$ ); b) and f)by the momentum ( $p_{lab}$ ); c) and g) by the longitudinal rapidity ( $Y_{lab}$ ); d)and h) by the azimuthal angle  $\cos\Theta$ (in the SM of p+p collisions).

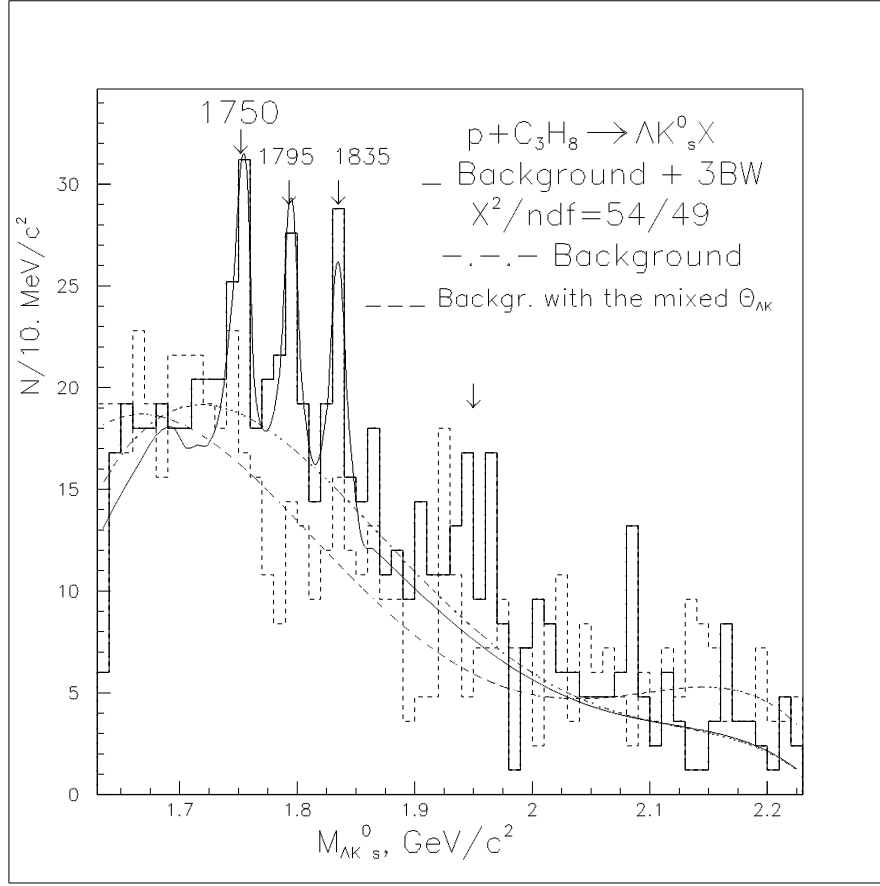


Figure 3: Invariant mass distribution ( $\Lambda K_s^0$ ) with the bin size  $10 \text{ MeV}/c^2$  in the inclusive reaction  $p + C_3H_8$ . The solid curve is the sum of the experimental background by the first method (the dot-dashed curve) and 3 Breit-Wigner resonance curves. The dashed histogram is the experimental background[25].



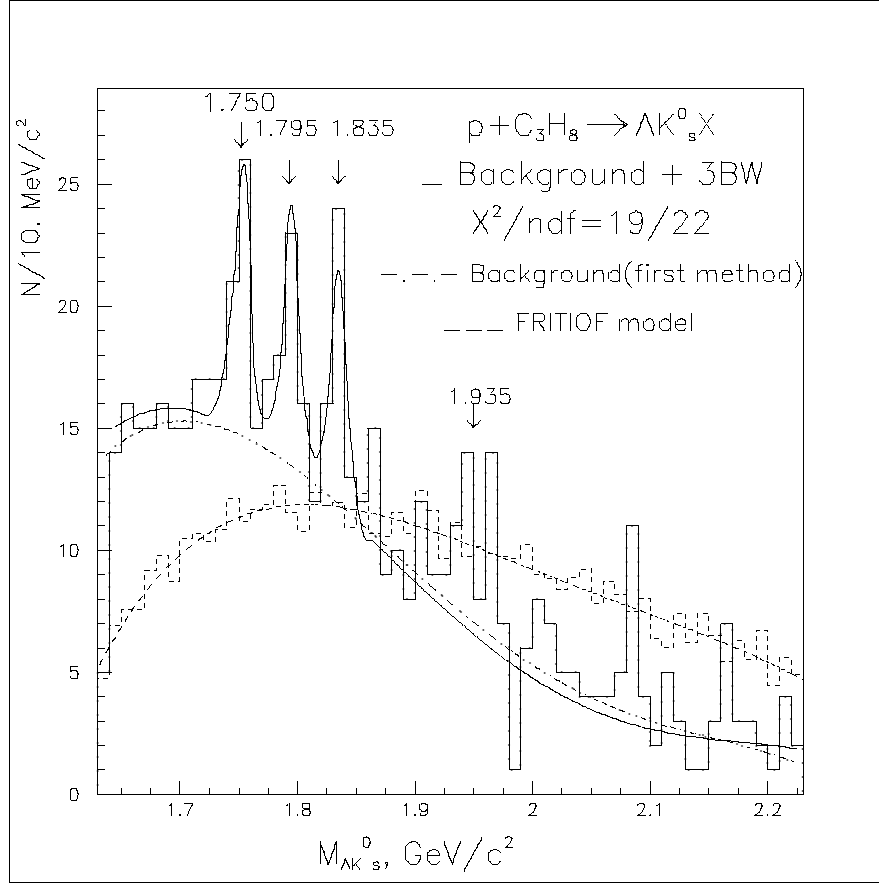


Figure 4: Invariant mass distribution ( $\Lambda K_s^0$ ) with the bin size  $10 \text{ MeV}/c^2$  in the inclusive reaction  $p + C_3H_8$ . The solid curve is the sum of the experimental background by the first method (the dot-dashed curve) and 3 Breit-Wigner resonance curves. The dashed histogram is the simulation by FRITIOF model[26,27].

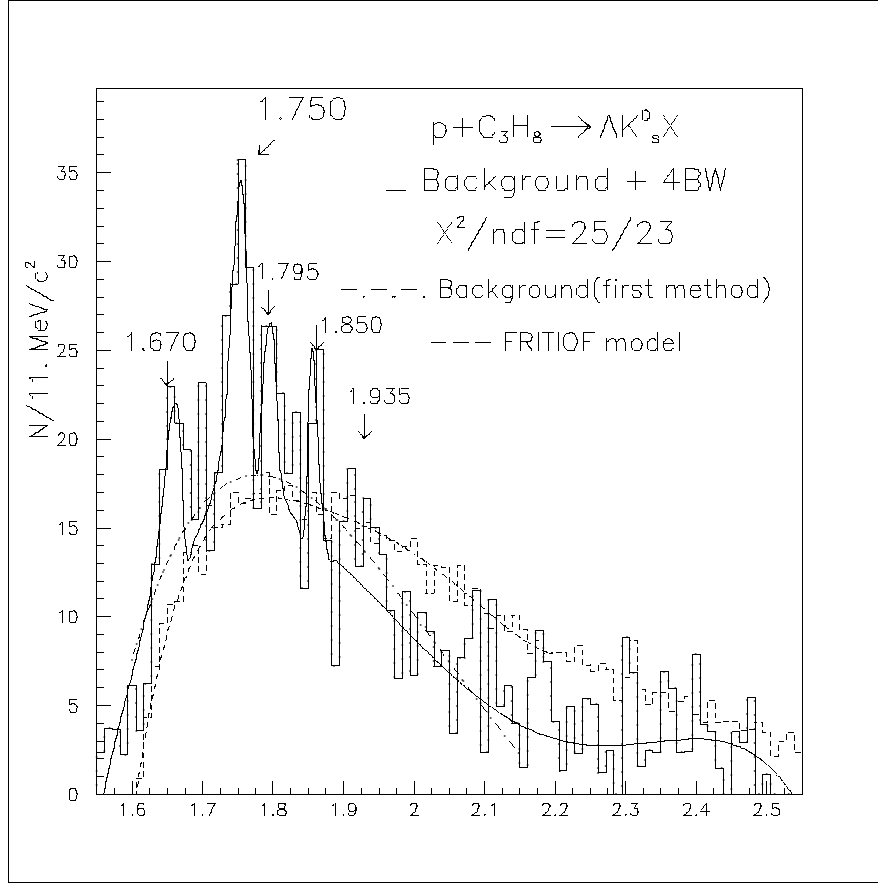


Figure 5: Invariant mass distribution ( $\Lambda K_s^0$ ) with the bin size  $11 \text{ MeV}/c^2$  in the inclusive reaction  $p + C_3H_8$ . The solid curve is the sum of the experimental background by the first method (the dot-dashed curve) and 4 Breit-Wigner resonance curves. The dashed histogram is the simulation by FRITIOF model[26,27].

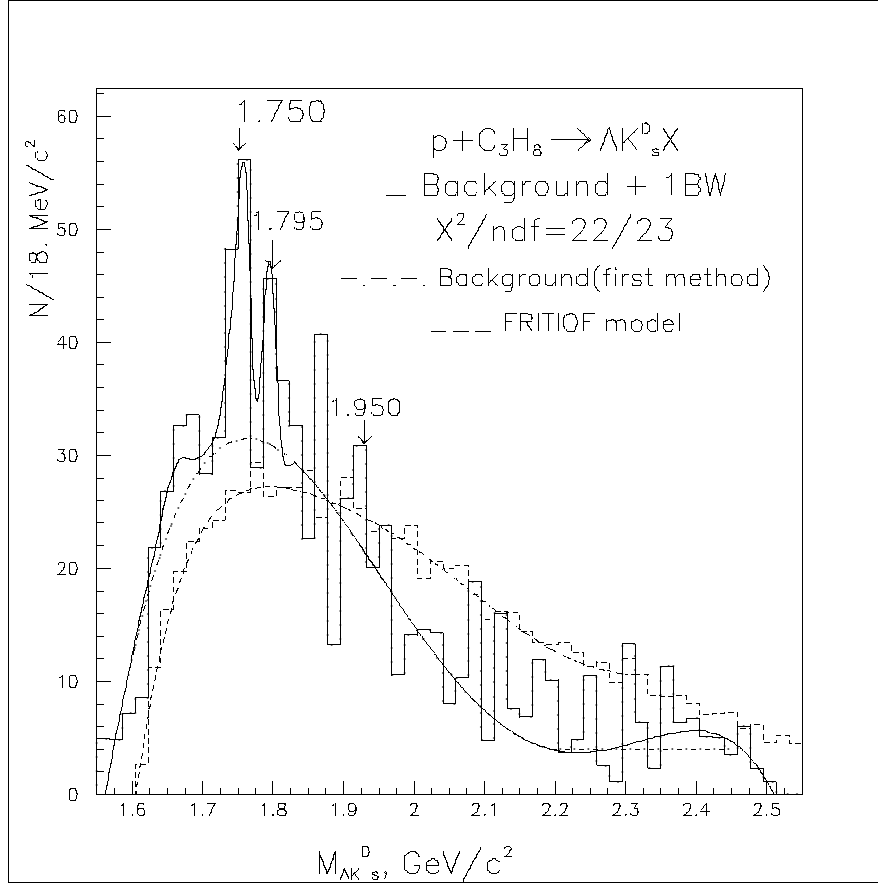


Figure 6: Invariant mass distribution ( $\Lambda K_s^0$ ) with the bin size  $18 \text{ MeV}/c^2$  with the bin size  $10 \text{ MeV}/c^2$  in the inclusive reaction  $p + C_3H_8$ . The solid curve is the sum of the experimental background by the first method (the dot-dashed curve) and 2 Breit-Wigner resonance curves. The dashed histogram is the simulation by FRITIOF model[26,27].